Empirical Validation of DesignBuilder Software for Simulating Environmental Parameters in a Classroom Environment

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ABSTRACT

Computer simulation is one of the best ways to comprehensively analyse the whole performance of buildings. Most of the recent researches conducted on the DesignBuilder validation were restricted to only one parameter out of the four conventionally known environmental parameters, however, this study takes all the four parameters in the validation, and empirical validation was adopted. The National Renewable Energy Laboratory (NREL), in collaboration with the International Energy Agency (IEA), developed several Building Energy Simulation Test, (BEST,) suites for validating software used for energy analysis of buildings. The results show that the r-values are at an average of 0.97 and p-values of 0.001 at a 95 % level of confidence for the 192 primary school classrooms. The lowest and highest MBE was – 0.21 and 0.99 (falling within the -15 to +15 range), while that of the RMSE was 1.02 and 6.29 (positive and less than 35%) respectively. The zonal percentage differences of environmental variables have the lowest being -8.60% and the highest 9.98% are all within the acceptable range (-10% to +10%). The software was validated as results conformed to the analyses using correlation tests, line graph comparisons, MBE, RMSE, and average percentage difference calculations. The study recommends that Architects and Government education policymakers encourage the use of DesignBuilder for simulation to aid in design decisions.

Keywords: classroom, DesignBuilder, environmental parameters, simulation, validation

INTRODUCTION

Simulation, mimicry of reality, in research has become an easier way of modelling and iterating reality with a certain degree of certainty while saving precious time and limited finances. It creates an artificial environment fulfilling all the real-time situations or depicting the exact similitude of a phenomenon. It is an imitative rendition of a procedure or system that could be obtained in the real world. Studies of complex systems are enabled as they generate observations by advancing into the future. One of the ideal methods for evaluating buildings' whole performance is computer simulation (Gunay, 2016; Isa, 2023; Prieto, 2017,).

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The use of building energy simulation programs can be done to accurately predict building performance (Apif, 2024; Clarke, 1998; Crawley, 2004). Computer simulation is one of the best ways to comprehensively analyze the whole performance of buildings. This approach can be applied to simulate buildings with varying climatic conditions. Studies have most often used the same methods to obtain results on the performance of buildings (Mateus, 2014). Previous research has shown that many simulators have been designed to simulate various energy-saving applications (Dahanayake, 2017). Some devices have been produced to analyze buildings' energy and thermal conditions (Kirimtat, 2016).

One of the distinct programs for simulating building energy is the DesignBuilder software. Most of the recent researches conducted on the validation were restricted to only one parameter (Habu, 2022; Tayari, 2023) out of the four conventionally known environmental parameters, however, this study takes all four parameters in the validation exercise which exudes more confidence and a robust outcome representative of the environmental parameters holistically.

There are several methods of validating thermal comfort analysis software Neymark (2020) and Magni, (2021) detailed some software validation procedures. These procedures are based on the International Energy Agency (IEA), Building Energy Simulation Test (BESTEST), diagnostic method which systematically test whole-building energy simulation software by comparing results from such software to developed analytical solutions. Building energy simulation tests have ways to evaluate the accuracy of a whole-building energy simulation program.

Validation of simulation software on building performance can be accomplished by applying three contrasting methods, these are analytic, comparative, and empirical.

ANALYTIC VALIDATION

This is a method in which outputs from a program, subroutine algorithm, or software object are compared to results from a known analytical solution or a generally accepted numerical method for isolated heat transfer mechanisms under very simple and highly constrained boundary conditions. This validation procedure is where experimental field measurements are compared with mathematical results (Tayari, 2023). However, these dynamic calculation procedures have complex calculation algorithms and require a more complex validation process.

COMPARATIVE VALIDATION

This is where a program is compared to itself or to other programs that may be considered better validated or more detailed and, presumably, more physically correct.

Empirical Validation: comparison of experimental measurement with simulation.

Empirical validation is where calculated results from a program, subroutine, algorithm, or software object are compared to monitored data from a real building, test cell, or laboratory experiment. Empirical validation is required when establishing a truth standard for evaluating the abil-

ity of a program to analyse real physical behaviour (Judkoff, 2014; Magni, 2021; Neymark, 2020). It is the validation method adopted by this research because of its obvious advantage and accuracy over the other validation methods.

This research aims to develop and validate simulation techniques and analyse the use of DesignBuilder to evaluate the performance of buildings. The results can be used in the preliminary stages of design or retrofitting existing structures to improve the building's energy performance which will ultimately improve the thermal conditions in the classrooms and equally give confidence in the performance of the software to upcoming researchers.

METHODS

The National Renewable Energy Laboratory (NREL), in collaboration with the International Energy Agency (IEA), developed many building energy simulation test, BESTEST, suites for validating software used for energy analysis of buildings. (Judkoff, 2013; Magni, 2021). Statistical tests for significance, correlation tests, descriptive statistics, Mean Bias Errors (MBE), and Root Mean Squares Error (RMSE) were employed to analyse the data. To ascertain the degree of accuracy of the correlations, two statistical methods for simulation study are acceptable and were employed, Mean Bias Error ((MBE) and Root Mean Square Error (RMSE). The MBE indicates the average deviation of the simulated values from the field values. It also gives information on the long-term performance of the models. Positive results show that the simulation results overestimate the field values and negative values show an underestimation of the field values (Abubakar, 2015). However, the RMSE is indicative of the variation of the simulated results around the field results and is always the positive percentile, giving the short-term performance of the models. In this case the lower the value the more accurate is the simulation prediction.

STUDY AREA

The warm semiarid climatic zone of Nigeria occurs in the northernmost parts of Katsina, Kano, Zamfara, Yobe, Jigawa, and Sokoto states. Sokoto, Katsina, and Jigawa states were randomly selected to represent the Western, Central, and Eastern axis respectively, of the warm semiarid climatic zone of Nigeria for this research, Figure 1 with a total population of 14,549 primary schools. All the selected states fall about the same latitude 12°30'N.



Fig. 1: Study area in Nigeria using Koppen climate classification. Source: Google MapS (2023)

The zone has more schools in the central and west areas than in the east, therefore 48,72, and 72 classrooms were sampled, pro rata based on the school population from each of the east, central, and west spread of the warm semi-arid climatic zones respectively. This gives a total sample size of 192 classrooms.

SIMULATION PROCEDURE

One of the recognized validation methods is empirical validation in which calculated results from a software object are compared to monitored data from a real building or laboratory experiment (Judkoff, 2014). The empirical validation procedure was consequently adopted in this study where the simulation results were compared with the real results measured in the field for validation, Figure 2.





Fig. 2: Empirical validation procedure

The empirical validation technique is the most pragmatic as it compares real results obtained from the field with simulation results from the computer model.

The following steps were adapted in the empirical validation procedure:

- i. Modelling of the classrooms as measured from the field
- ii. Inputting relevant EnergyPlus (EPW) weather files for specific locations
- iii. Inputting the relevant simulation parameters
- iv. Running the simulation
- v. Comparison of measured field results and the simulated results for validation
- vi. Making inferences from the comparison for validation.

ANALYTIC TOOLS AND METHODS OF DATA PRESENTATIONS

Data in itself only makes sense when it is systematically analysed with appropriate tools and its presentation is shown in a discernable manner from inferences that can be drawn ultimately.

Data Presentations Methods

For the validation, the various values of the variables for the simulated and field measured results were analysed visually using line graphs for comparison. Equally some data and results are presented in tabular forms and figures.

Analytic tools

Statistical tests for significance, correlation tests, descriptive statistics, mean bias errors (MBE) and root mean squares error (RMSE) were employed to analyse the data. To ascertain the degree of accuracy of the correlations, two statistical methods for simulation study are acceptable and were employed, Mean Bias Error ((MBE) and Root Mean Square Error (RMSE). The MBE indicates the average deviation of the simulated values from the field values. It also gives information on the long-term performance of the models. Positive results show that the simulation results overestimate the field values and negative values show an underestimation of the field values. However, the RMSE is indicative of the variation of the simulated results around the field results and is always in positive percentile, giving the short-term performance of the models. In this case the lower the value the more accurate is the simulation prediction.

The formulae for the mean bias error (MBE) and root mean square error (RMSE) are expressed as:

 $\%MBE = 100/x_{w} \Sigma (x_{c} - x_{w}) /N$

$$xRMSE = \frac{100}{x_{av}} \sqrt{\frac{1}{N}} \sum (x_s - x_m)^2$$

Source: (Efim & Kudish, 2009, Katiyar et al., 2010).

Where: X_{sim} is the simulated variables results; X_{mea} is the field measured variables results; X_{av} is the average value of N measured variable values.

The software packages used are DesignBuilder, AutoCAD 2018, SPSS 23, and Microsoft Excel. The simulation analysis conducted entails the design of a basic model as a basis for the various class-room elemental permutations. Parametric and non-parametric tests are the two inferential statistical tests for use with data, though parametric is more powerful. For the parametric tests to

be conducted the data must be normally distributed. Shapiro-Wilk test and Kolmogorov-Smirnov normality tests were conducted. Inferential statistics was executed with the aid of SPSS and Excel using T-Test, ANOVA, repeated measures ANOVA, and Regression analysis. Action and intervention models were generated with the aid of Designbuilder software with an Energyplus simulation engine giving results of the thermal performance of the classrooms.

FINDINGS

Measurements were taken in April/May (hottest months), August/September (rainy season), and December/January (coolest months). This was to gather within the year, climatic representative data from all the thermally influential seasons in the warm semiarid climatic zone.

Comparative Analysis of Field-Measured & Simulated Results

The field and simulated results were obtained in line with the building energy simulation test (BESTEST), International Energy Agency (IEA) as well as ASHRAE standard procedures. The averages of the field measured and simulated data and measurements are presented in Table 1.

Variable	Simulation results	Field results	Average	Error (sim-meas)	Error 2 (sim-meas)
Air temperature (°C)	37.78	35.38	36.58	2.4	5.76
Radiant temperature (°C)	40.30	37.33	38.82	2.97	8.82
Air velocity (m/s)	0.58	0.53	0.56	0.05	0.003
Outdoor temperature (°C)	38.10	39.30	38.70	-1.19	1.42
Relative humidity (%)	29.44	35.60	32.52	-6.16	37.95
Operative temperature (°C)	39.10	36.36	37.73	2.74	7.51

Table 1:Zonal simulation and field results

Source: Authors (2023)

The difference between the simulated and field results shows a minimal variation signifying a significant agreement between both results strengthening and validating the software, Table 1.

Visual analysis

The presentation in table 1 does not easily show the relationships between the field and simulated results. However graphical representations of these relationships depict the qualitative agreement between the field and simulated variables results, in Figure 2.

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Fig. 2: Warm semiarid zonal mean field and simulated environmental parameters comparison. Source: Author (2023)

TEST OF RELATIONSHIP AND SIGNIFICANCE

For a strong positive or negative linear correlational relationship, an r-value has to fall between -1 to +1. It could be seen that all the r-values show a strong positive linear correlation between the field and simulated variables results in all the classrooms. In addition, for a relationship to be considered as being significant it should have a p-value of less than 0.05 at a confidence level of 95%. The significance, p-value, for the classes in the 192 primary classrooms is 0.002 for Hadejia zone (East axis), 0.003 for Gumel zone (Central axis), 0.00 for the Sokoto zone (West axis), and a zonal average of 0.001 where all are less than 0.05 threshold, thereby indicating that the relationship between the field and simulated variables results is significant as depicted in Figure 3:





Fig. 3: Zonal correlation for field and simulated results (r = 0.97, $r^2 = 0.95$, p = 0.001). Source: Authors (2023)

The results for the test of significance from Table 2 were obtained by applying the formula:

$$t = r \sqrt{\frac{n-2}{1-r^2}}$$

Sn	Location	r	r ²	df=n-2	t critical	t observed	Inference
1	East	0.96	0.92	7	1.89	8.98	t _{observed >} t _{critical} significant
2	Central	0.95	0.91	7	1.89	8.38	t _{observed >} t _{critical} significant
3	West	0.99	0.98	7	1.89	18.52	t _{observed >} t _{critical} significant
	Zonal	0.97	0.94	7	1.89	10.48	t _{observed >} t _{critical} significant

 Table 2:
 One-tailed test of significance

Source: Authors (2023)

The result in Table 2 above signifies that there is a strong relationship in all locations within the region and the relationship between the simulated and the field-measured values of the environmental variables is significant.

Mean Bias Error (MBE) and Root Mean Square Error (RMSE)

As explained in the previous section, to ascertain the degree of accuracy of the correlations, two statistical methods for simulation study are acceptable and were employed, Mean Bias Error (MBE) and Root Mean Square Error (RMSE). The MBE indicates the average deviation of the simulated values from the field values while the RMSE is indicative of the variation of the simulated results around the field results (Reinhart, 2009). For simulation data to be acceptable as reliable, the mean bias error should fall within the -15 to +15 range and the root mean square error should have a value that is positive and must be less than 35%, Tables 4.

Environmental variable	N	Σ X _{sim} -X _{mea}	X _{av}	$\Sigma (X_{sim} - X_{mea})^2$	% MBE	% RMSE
Air temperature (°C)	9	2.4	36.58	5.76	0.73	2.18
Radiant temperature (°C)	9	2.97	38.82	8.82	0.85	2.54
Air velocity (m/s)	9	0.05	0.56	0.003	0.99	3.24
Outdoor temperature (°C)	9	-1.19	38.70	1.42	0.40	1.02
Relative humidity (%)	9	-6.16	32.52	37.95	-2.10	6.29
Operative temperature (°C)	9	2.74	37.73	7.51	0.80	2.41

Table 3:Zonal mean bias error and root mean square error.

Source: Author (2024)

AVERAGE ENVIRONMENTAL VARIABLES CALCULATIONS

A guide for the determination of the accuracy level of validation results was put forward by the Commission Internationale de L'Eclairage with the use of the averages of simulated and field-measured results. The formula for calculating the percentage difference of the simulated from the field measured results is as given below:

% $Diff = 100 x_{sim(av)} - x_{mea(av)} / x_{mea(av)}$

Table 4:Averages of simulated and field-measured results

	Axes	X mea(av)	X sim(av)	%Diff				
East	East axis (Hadejia)							
1	Air temperature (°C)	37.56	35.54	-5.38				
2	Radiant temperature (°C)	37.2	36.3	-2.42				
3	Air velocity (m/s)	0.61	0.50	-18.03				
4	Outdoor temperature (°C)	36.3	35.7	-1.65				
5	Relative humidity (%)	47.95	51.35	7.09				
6	Operative temperature (°C)	37.38	35.92	-3.91				
Central axis (Gumel)								

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	Axes	X mea(av)	X sim(av)	%Diff			
1	Air temperature (°C)	37.78	33.30	-11.86			
2	Radiant temperature (°C)	47.83	38.99	-18.48			
3	Air velocity (m/s)	0.55	0.59	7.27			
4	Outdoor temperature (°C)	34.64	39.70	14.60			
5	Relative humidity (%)	30.92	30.80	-0.39			
6	Operative temperature (°C)	42.81	36.15	-15.56			
West	West axis (Sokoto)						
1	Air temperature (°C)	38.35	37.30	-2.74			
2	Radiant temperature (°C)	35.87	36.70	2.31			
3	Air velocity (m/s)	0.57	0.50	-12.28			
4	Outdoor temperature (°C)	43.4	42.50	-2.07			
5	Relative humidity (%)	13.45	15.0	11.52			
6	Operative temperature (°C)	37.11	37.0	-0.30			

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Fisher (1992) advanced that the percentage differences between simulated and measured values in space is acceptable if they fall within a range of -10% to +10% difference. Source: Authors (2024)

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	Parameter	X _{mea(av)}	X _{sim(av)}	% Diff
1	Air temperature (°C)	37.78	35.38	-6.35
2	Radiant temperature (°C)	40.30	37.33	-7.37
3	Air velocity (m/s)	0.58	0.53	-8.60
4	Outdoor temperature (°C)	38.10	39.30	3.15
5	Relative humidity (%)	29.44	35.60	9.98
6	Operative temperature (°C)	39.10	36.36	-7.00

Source: Authors (2024)

The zonal average values have satisfied the requirements for acceptance and validation have all fallen within the range of -10% to +10%.

DISCUSSION

The correlation test between the measured and simulated results shows that the r-values are at an average of 0.97 and p-values have an average of 0.0016 at a 95% level of confidence. In all cases, this signifies a strong positive linear correlation and strong significance between the field and simulated variables results as a requirement for accepting the simulated results and validation of the software. The zonal percentage differences of environmental variables have the lowest being -8.60% and the highest 9.98% all within the acceptable range (-10 to +10) as depicted on the zonal average summary table. The lowest and highest of the Mean Bias Error (MBE) are- 0.21 and 0.99

(fall within the -15 to +15 range), while the Root Mean Bias Error (RMSE) are 1.02 and 6.29 (positive and less than 35%) respectively, as shown on Table 4. All the results obtained agree with the positions of scholars in the field of simulation such as Reinhart (2009), Falayi *et al* (2011), Abubakar (2015), Salihu, (2021), and Musa, (2022).

CONCLUSION

The various methods for validation of software results obtained from the field when compared to that of the DesignBuilder computer simulation were in agreement and were within the acceptable ranges. The software was validated as both results conformed to the analyses using correlation tests, line graph comparisons, mean bias error (MBE), root mean square error (RMSE), and average percentage difference calculations. Consequently, the software had, within the limits of experimental error and acceptability, replicated real-life scenarios and is therefore validated. The study, therefore, recommends to Architects and the Government education policymakers the advantages of the use of DesignBuilder for simulation which aids in design decisions for both new classrooms and retrofitting of existing ones, all geared towards enhancing thermal comfort for ultimately optimising learning.

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